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PULSARSPECTRUM: SIMULATING GAMMA-RAY PULSARS FOR THE GLAST MISSION

MASSIMILIANO RAZZANO, LUCA LATRONICO, NICOLA OMODEI,
GLORIA SPANDRE

Istituto Nazionale di Fisica Nucleare, sezione di Pisa,
Largo B.Pontecorvo 3, 56100 Pisa
E-mail: massimiliano.razzano@pi.infn.it

We present here an overview of *PulsarSpectrum*, a program that simulates the gamma ray emission from pulsars. This simulator reproduces not only the basic features of the observed gamma ray pulsars, but it can also simulate more detailed effects related to pulsar timing. It is a very useful tool to understand the GLAST capabilities in the pulsar science.

1. Introduction

Pulsars are among the most exciting gamma ray sources in the Universe and can serve as unique sites for the study of emission processes in extreme physical environments. The Gamma ray Large Area Space Telescope (GLAST) will increase dramatically our knowledge of gamma ray pulsars physics. In particular the Large Area Telescope (LAT), the main GLAST instrument, will provide more detailed observations of the known gamma ray pulsars and potentially will discover many new pulsars that emit gamma rays. To better understand the capabilities of GLAST for pulsar science we developed *PulsarSpectrum*, a program that simulates gamma ray emission from pulsars. This simulator can be easily interfaced with the Monte Carlo software that simulates the response of the LAT.

1.1. *Gamma ray pulsars in the GLAST era*

Pulsars have been associated with high energy gamma ray astronomy since the first experiment capable to resolve point sources. The *Small Astronomy Satellite*(SAS-2), launched in 1972, identified three intense sources in the sky, that in the following turned out to be the Vela, Crab and Geminga pulsars. A signal modulated at the radio period was found for Vela [1] and

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Crab [2], but for Geminga no radio counterpart was found and this source remained quite mysterious until it was identified as an X-ray and gamma-ray pulsar. The *Energetic Gamma Ray Experiment* (EGRET) aboard the *Compton Gamma Ray Observatory* (CGRO) detected three more pulsars, B1706-44 [3], B1055-52 [5] and later B1951+32 [9]. Another one, B1509-58 was observed at energies between 60 keV and 2 MeV by the three CGRO experiments, the *Burst and Transient Source Experiment* (BATSE)[7], the *Oriented Scintillation Spectrometer Experiment* (OSSE), [6] and the *Imaging Compton Telescope* (COMPTEL)[4], but it was not seen by EGRET, because the spectrum shows a cutoff at energies lower than the instrument's threshold. Recently the millisecond pulsar PSR 0218+4232 was detected by analyzing the EGRET data [10], increasing to eight the number of detected gamma ray pulsars, seven of them are radio-loud pulsars and only Geminga seems to be radio quiet.
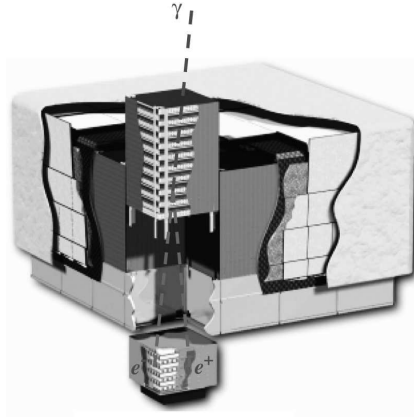

Figure 1.   The GLAST Large Area Space Telescope. An incident gamma ray converts into a e^-e^+ pair

The GLAST Large Area Telescope (LAT) (fig 1), is a pair conversion telescope based on the most advanced high energy detectors. It consists in a precision silicon strip tracker, a hodoscopic calorimeter and a segmented anticoincidence shield for particle background rejection. The LAT high sensitivity ($2\ 10^{-9}$ ph/cm^2/s) and effective area (>8000 cm^2) will permit the discovery of a lot of new pulsars: the estimates range between tens to hundreds depending upon the model adopted. Moreover the low dead time of the detector (20 μs) will allow the detailed reconstruction of pul-

sar lightcurves. One of the most exciting possibilities of the LAT will be the coverage of the energy window from 30 GeV up to 300 GeV, a still unexplored range. At these energies the theoretical models make different previsions on the high energy spectral cutoff and the spectral coverage of LAT will be of primary importance for constraining and discriminating among the models. In order to study the LAT response to specific gamma ray sources, various simulation packages have been developed. Here we present *PulsarSpectrum*, that can simulate the observed pulsars and create new fake pulsars for the LAT threshold detection identification.

2. The *PulsarSpectrum* simulator

2.1. *Overview of the simulator*

The basic idea behind *PulsarSpectrum* is to construct a 2-dimensional histogram representing the differential flux vs. energy and pulsar phase. This histogram contains all the basic informations about lightcurve and spectrum. How it is built depends upon the model we want to use: a phenomenological model, based only on observations, or a physical one, based on a specific theoretical model. At present only a phenomenological model has been implemented because it is more flexible and completely independent from the chosen theoretical scenario. The input parameters of the simulator can be divided in two categories:

- *Observational parameters*, (i.e the flux or the ephemerides);
- *Model-dependent parameters*, (i.e. the spectral index);

These parameters are placed in two specific data files used by both *PulsarSpectrum* and the LAT simulation tools. *PulsarSpectrum* creates the lightcurve and the spectrum from these parameters and combines them to obtain a two-dimensional matrix that represents the flux in $ph/m^2/s/keV$. The photons are then extracted such that the interval between two subsequent photons is determined by the flux integrated over the energy range of interest.

2.2. *The phenomenological model*

The currently implemented phenomenological model allows the user to generate pulsar lightcurves in a general way using a single or double Lorenzian peak profile whose shape is determined from random generated numbers. The lightcurve can be generated alternatively from a user-provided profile. This is useful for simulating the already observed gamma ray pulsars.

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The spectral shape is assumed to be a power law with exponential cutoff (according to [8]), as in the observed gamma-ray pulsars and can then be modeled as:

$$\frac{dN}{dE} = K(\frac{E}{E_n})^a exp(\frac{E}{E_0})^{-b} \tag{1}$$

The normalisation constant K is determined by the photon flux above 100 MeV and the other four parameters can be varied; the values for the EGRET pulsars are obtained from real data by fitting procedures (e.g. [8]).
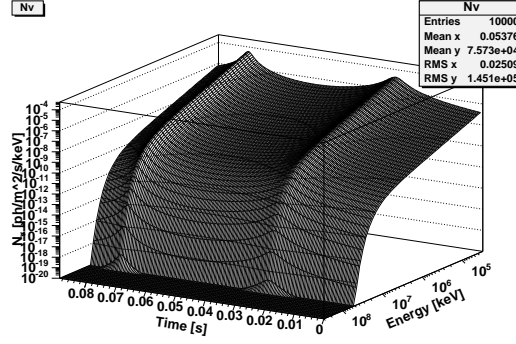

Figure 2.   An example of 2-dimensional histogram created by PulsarSpectrum.

2.3. *Timing issues*

Once the differential flux histogram is created the time interval between two subsequent photons is computed according to the flux. If the previous photon came at time t_0 the next photon will appear at $\tilde{t}$ such that:

$$A_{eff} \int_{t_0}^{\tilde{t}} \int_{E_1}^{E_2} \frac{dN}{dEdAdt} \, dEdAdt \ = 1 \tag{2}$$

The interval between two photons is computed assuming that the pulsar period does not change with time and the photons arrival times are computed into a reference system fixed relative to stars. This is not the "real world". Pulsar timing is affected by more complicate effects, as (1)- The motion of the spacecraft through the Solar System and the relativistic effects due to gravitational well of the Sun (see 2.3.1); (2)- Period changes with time (see 2.3.2). For pulsars in binary systems an additional modulation to the

orbital period should be taken into account. For a precise pulsar simulator intent to produce a realistic list of photon arrival times we need to include all these effects (to transform to the observational frame). All these procedures are now implemented in the code and only the binary demodulation is not yet implemented. The real arrival time of a photon from a pulsar must be first barycentered and then phase assigned.

2.3.1. Barycentric effects

The first step to analyze pulsar data is the conversion from the arrival times at the spacecraft, usually expressed in Terrestrial Time TT or TAI, to the arrival times at the Solar System barycenter, expressed in Barycentric Dynamical Time TDB. Taking into account both the motion of spacecraft through space and the general relativistic effects due to the gravitational field of the Sun (i.e. Shapiro delay), the simulator computes the opposite of the barycentric correction by considering the position of the Earth and of the spacecraft in the Solar System, and the position of the Sun. The accuracy for the computation of these "de-corrections" is hard-coded in the program.

2.3.2. Period change and ephemerides

The rotational energy of a radio pulsar decreases with time and hence the period increases with time. For gamma ray pulsar science the radio ephemerides are fundamental for assigning the correct phase to each photon. If we know the frequency $f(t_0)$ and its derivatives $\dot{f}(t_0)$ and $\ddot{f}(t_0)$ at a certain time t_0, known as *epoch*, the phase is then:

$$\phi(t) = int[f(t_0)(t - t_0) + \frac{1}{2}\dot{f}(t_0)(t - t_0)^2 + \frac{1}{6}\ddot{f}(t_0)(t - t_0)^3]. \qquad (3)$$

The interval between two photons must be "de-corrected" for this effect. In the parameters file the user can specify a set of ephemerides with the relative epoch of validity expressed in Modified Julian Date. The simulator then computes the opportune arrival time such that, after applying the barycentric corrections and the equation 3, the correct phase is obtained.

3. Conclusions

PulsarSpectrum has been successfully used by the GLAST collaboration for testing the functionality of the LAT Science Analysis Tools, a set of analysis programs specifically designed to analyse the LAT data after launch.
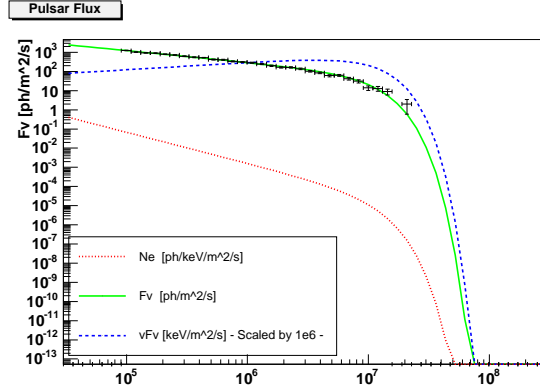
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Figure 3.   An example of the spectrum of a simulated pulsar created by PulsarSpectrum. The point represents the extracted photons of energy above 100 MeV.

Periodically these tools are evaluated through specific Checkout phases. In absence of real data there is strong need of detailed simulated data, most of them provided by *PulsarSpectrum*. *PulsarSpectrum* is the most probable candidate to be used as pulsar simulator in the GLAST Data Challenge 2, an analysis phase where some months of LAT data are simulated. A new interesting opportunity is now raising from the creation of the LAT Science Groups, to study GLAST science opportunities on specific topics. Our simulator has all the characteristics to fit well the requirements of the LAT Pulsar Science Group.

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